DRAFT for Comment

MCAS Technology Development Plan

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Introduction

The primary objective of Micro Communications and Avionics Systems (MCAS) effort is to develop telecommunications systems to meet the unique needs of NASA's missions requiring short range, low power, space and planet-surface communications. NASA is moving into an era of much smaller space exploration platforms that require low mass and power. This new era brings increasing numbers miniature rovers, probes, landers, aerobots, and multiplatform instruments, all of which have short range communications needs (in this context short range is defined as non-DSN links). Presently these short range communications needs are being met by a combination of modified commercial solutions (e.g., Sojourner) and mission specific designs (e.g., Mars Global Surveyor and Mars '98). These short-range communication systems are relatively large, require high DC power, or do not provide the performance and capabilities to make them viable candidates for future missions.

The goal of MCAS is to identify technology long poles and work to remove them. Specifically MCAS will strive to: 1) achieve a reduction of size and power of short range space communications systems through custom integrated designs, 2) provide sufficient performance and flexibility to allow use by a variety of mission sets, 3) explore incorporation of breakthrough technologies (e.g., MEMS oscillators/filters).

A survey of present and future NASA planetary missions with short range communication needs has been conducted. The missions include like Mars Pathfinder, '98 Lander, '98 Microprobes, '01 Lander and Rover, and '03 Lander and Rover, New Millennium Deep Space 3 (DS-3) Interferometry, Champollion (DS-4), Muses-CN Nano-Rover, Venus Geoscience Aerobt Study (VEGAS), Free Flying Magnetometer, and several Discovery proposals. While each mission has a different set of requirements for the communication system, the missions also have many requirements in common.

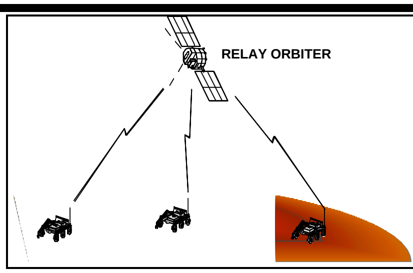
MCAS will focus on advancing technologies and building a transceiver that can meet the requirements of planetary missions. The transceiver will have a high level of integration at the chip level thus allowing significant mass, power, and size reductions at lower cost for a broad class of very small platforms that require short range communications. MCAS will build on the efforts currently being undertaken on the New Millennium Deep

Space 2 (DS-2) highly integrated transceiver, but with an eye toward more multimission applicability. MCAS is a multiphase effort that will evolve over time taking advantage of advances in communications IC technology that will lead to increasingly more integrated solutions. MCAS will target missions of opportunity for rapid insertion and demonstration of the developed technology while at the same time continue to progress toward the long range vision of a telecom "system on a chip".

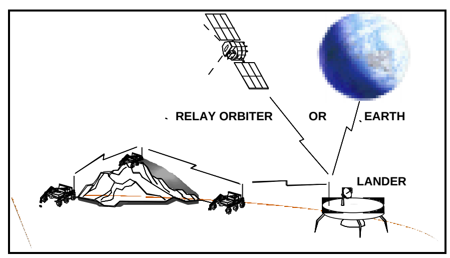
NASA's Short Range Communications Mission Needs

Figure 1 depicts a sampling of the types of NASA missions that have short range communications needs. All of these missions could benefit from a reduction in the size and power consumption of their respective communication systems. The broad range of communication system requirements depicted obvious rules out any single solution that could be utilized by all missions, yet the underlying technologies that MCAS will attempt to advance are equally applicable to this entire mission set.

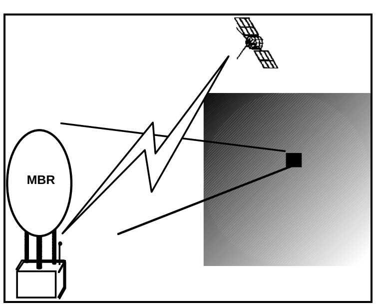
In a rough sense these missions can be partitioned into short range planetary missions (1 km to 40,000 km) and other ultra short range missions («1 km). Though the MCAS effort is necessarily focused on the short range planetary missions because of the perceived immediate need, this will not be to the exclusion of ultra short range missions which will be incorporated into the effort as well.



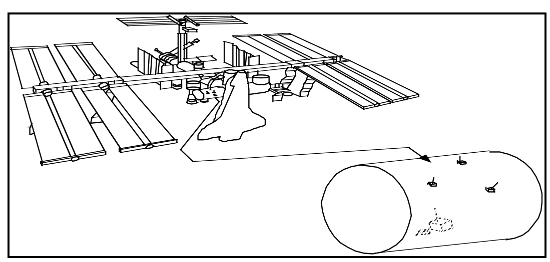
Surface-to-Relay Orbiter



Surface-to-Surface-to-Orbiter



Aerobot-to-Orbiter


Wireless Vehicle Health Monitoring Sensors

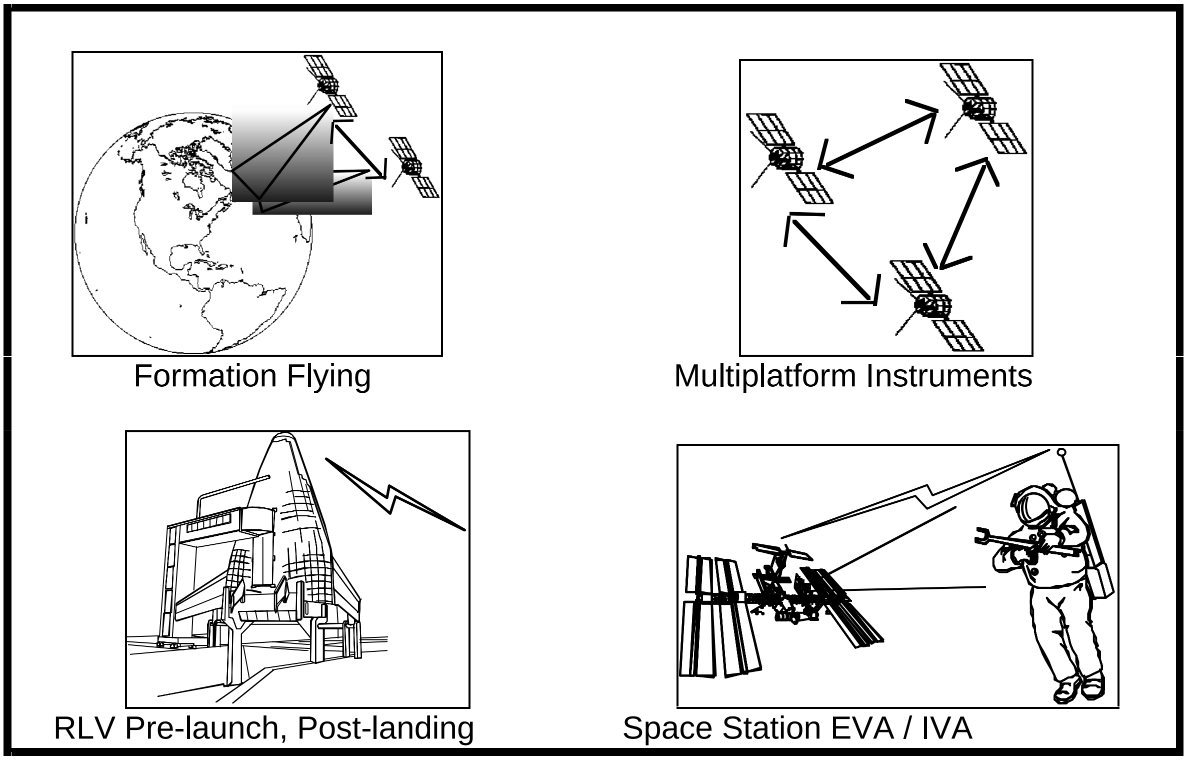


Figure 1 Sampling of NASA Missions with Short Range Communications

Planetary Missions (maximum range: 1 km to 40,000 km)

The planetary missions surveyed can be classified into four categories based on the command and telemetry data rates and the propagation environment as shown in Figure 2. Typically, planetary missions have asymmetric links with the data rate of the command link several orders of magnitudes lower than the data rate of the telemetry link. There are some future missions that require bi-directional high data rate command and telemetry links. The channels in which the communication systems operate are either free space or surface channels. In a free space communication channel, there is usually a direct line-of-sight signal, but little or no reflected or diffracted signals at the receivers. Signal attenuation is proportional to the square of the distance between the transmitter and the receiver. In a surface communication channel, both the transmitter and the receiver are on the surface of the planet/moon/comet/asteroid. The channel depends heavily on the environment. There may not be a direct line-of-sight between the transmitter and the receiver. A transmitted signal may travel through several different paths bouncing off different objects at different distances and arrive at the receiver with different delays and amplitudes. These multipath components of the received signal can add constructively or destructively resulting in distorted signal.

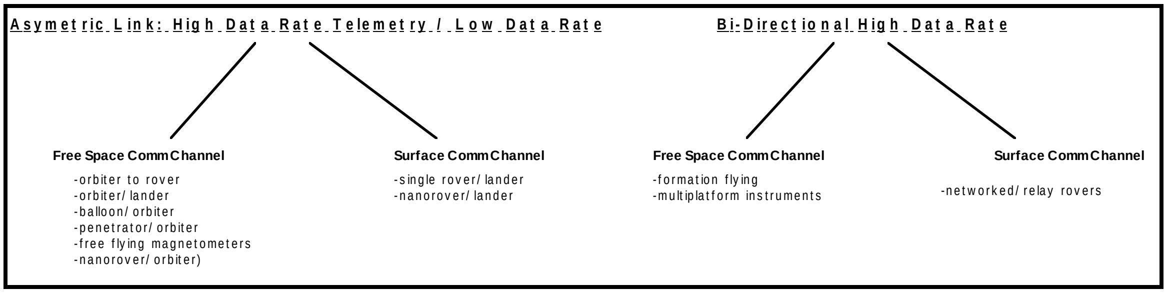


Figure 2 Categories of Short Range Mission Needs.

The missions that have asymmetric links with free space communication channels generally include an orbiting relay element and a surface element. The orbiting element is typically a relay satellite or balloon carrying a communication package to relay signals between surface elements and the Earth. A surface element can be a stationary lander, a penetrating probe, or a moving rover. Most future planetary missions with short-range telecommunication needs fall in this category. There are also missions with asymmetric links operating in surface communication channels of which the Mars Pathfinder is an example.

Some future missions have a need for bi-directional high data rate links. These missions require the exchange of data and commands for telemetry data gathering or processing. The New Millennium Deep-Space 3 Interferometer (DS-3) is an example of bi-directional high data rate link system in the free space channel. A network of rovers that exchange information to set up the proper relay network or perform parallel processing of the data is an example of a bi-directional high data rate link system in the surface channel.

Ultra Short Range Mission Needs (maximum range «1 km)

Besides the planetary missions with short-range telecommunication needs, there are various other NASA missions that have similar requirements. For example the reusable launch vehicle (RLV) has need for a high bandwidth wireless short range communication link just prior to launch and immediately after landing in order to rapidly assess the status of the vehicle remotely. Short range body-worn sensors with wireless transceivers would allow for unobtrusively monitoring the vital signs of the astronauts internal to the space station. The range for such sensors is approximately 1 meter and the transceivers need to be very small and light-weight. This type of astronaut communication is in addition to the desire to establish high data rate link between extra-vehicular-action (EVA) astronauts and the shuttle/space station for the transmission of real-time video. Additionally, there is a group of short-range communication systems coupled with various sensors to monitor the vehicle health of the RLV, space shuttle, and space station. The range for these transceivers will be up to 10 meters and they would be required to operate in an environment with very strong reflected signals from the surrounding spacecraft structure.

MCAS Trade-Off and Specifications

This section discusses the various trade-offs that are considered in arriving at a candidate MCAS specifications. The trade space includes frequency, modulation, coding, and compatibility with future systems such as Mars '01 Relay. As mass and power are at premium, the main goal is to design transceivers that are compact, low power, and light weight. These transceivers can be used by a master unit (MU) or a remote unite (RU). A master unit is defined as the master of a relay network. It can be an orbiter that relays messages to and from the Deep Space Network (DSN) and the landers and rovers on a planet. A remote unit can be a lander, a rover, a penetrator, or a balloon which does not have the capability to communicate directly with the DSN and relies on a relay package to communicate with Earth.

Frequency

Unlike communication near the Earth, the short-range planetary communication systems do not need to comply with frequency regulations. The 400 MHz UHF band is chosen for MCAS transceivers. In a relay environment, both the RU's and the relay usually have omni-directional antennas with gain independent of frequency. Propagation loss is inversely proportional to the square of frequency. Propagation loss at 400 MHz is significantly lower than at the 900 MHz and 2 GHz bands which are used for commercial short range communications. This advantage makes up for the higher galactic background noise at 400 MHz. The 400 MHz frequency band is also compatible with the existing Mars relay communication architecture. The disadvantage of the 400 MHz band is the large size of circularly polarized antennas which are also heavy (1 to 1.5 Kg) compared to the antennas for the 900 MHz and 2 GHz bands. This problem can be circumvented by using a monopole antenna or antennas made of advanced light-weight composite materials. The DS-2 transceiver, which uses the 400 UHF band, chooses a titanium monopole antenna which is small and light-weight. The antenna suffers a 3 dB polarization loss and a null at zenith. The polarization loss is easily compensated by the lower propagation loss at 400 MHz over the 900 MHz and 2 GHz systems. The null at zenith can severely degrade the link performance, but it only affects the link performance at large elevation angles and can be overcome by an acknowledgment protocol. An effort to design 400 MHz circularly-polarized antennas using advanced material to reduce the mass and volume has started under the funding of TMOD. A separate proposal has been also submitted to SOMO. Funding for the proposal is expected to start in Fiscal Year 1999.

Modulation

In a short-range relay system, the RU's can be severely power-constrained. BPSK should be used for the RU telemetry transmitter because of its power efficiency. No residual carrier is needed as the data rate is sufficiently high. BPSK should also be used for the RU command receiver. In a Mars relay system, the RF transmit power of 300 mW is needed for low data rate RU's with concatenated codes as in the case of DS-2. The DC power needed for the transmitter is expected to be much larger than the DC power of a RU BPSK or noncoherent command receiver. There is an additional advantage of choosing BPSK for the RU command link beside reducing the relay transmit power. Symmetric BPSK links allow two RU transceivers to communicate with one another as envisioned for future Mars landers and rovers.

Coding

Coding such as the concatenated code of (7,1/2) convolutional code and (255,233) Reed-Solomon code should be implemented for telemetry link from RU's to the relays. It is expected that future relay package such as the Mars '03 Relay will have Viterbi decoders. The Reed-Solomon decoding can be performed on Earth at the expense the lower efficiency of the DSN link. To reduce the DC power of the RU transceiver, the command link should be uncoded. Today, a commercially available Viterbi decoder chip consumes approximately 0.5 W of power which is significant for a low-power RU. Unless a low-power decoder chip can be found or if the decoder is incorporated into the transceiver ASIC, the relay spacecraft should provide the necessary transmitting power to ensure command data integrity. More powerful codes such as turbo codes should be consider for future relate systems as well.

Data Rates

The data rate of asymmetric-link communication systems is usually around 1 to 8 Kbps for the command link. The exceptions are Mars '98 Microprobes which use discrete tones for command and DS-3 where a large volume of commands is needed for formation flying. The telemetry data rate is between 8 Kbps to 2 Mbps. The telemetry data rates can be classified into two categories: low rates of around 8 Kbps and high rates of 64 Kbps to 256 Kbps. Only the New Millennium Deep Space 3 (DS-3) Interferometry mission requires the 2 Mbps high data rate. This requirement may be revised later.

Mass and Power

The mass and power requirements of the communication systems depend on the range and data rate of the links and environmental variables such as radiation and operating temperature, although the requirements are generally very tight. The communication system of Mars ‘98 Microprobes, for example, transmits at 300 mW RF with 430 mW of power supply and is very light-weight. Champollion/DS-4 requires the full-duplex transceiver system including the antenna to be less than 1.5 kg.

Range

The range for short-range planetary communication systems ranges from less than 1 Km to 40,000 Km. The nominal range for Mars missions with orbits like Mars Global Surveyor and Mars ‘98 Relay is about 400 Km to 1200 Km for surface elements. Comet missions typically have ranges less than 150 Km. One of the discovery proposals includes an orbiter in a highly elliptic orbit. The maximum range is 40,000 Km.

Full vs. Half-duplex

Due to the large propagation delay between the operators on the Earth and the remote elements, real time command is unlikely. Most of missions operate in half-duplex where simultaneous telemetry and command communication is not possible. The only exception where full-duplex communication is required is Champollion/DS-4. In Champollion/DS-4, mission designers do not wish to be constrained by communication opportunities due to the environmental unknowns of the comet.

Temperature

The temperature requirements of the planetary communication systems are more stringent than most of the commercial systems. Commercial systems typically operate between 0 C to 70 C. The planetary systems, however, may need to operate in temperature of -80 C where the performance of commercial systems may degrade significantly.

Radiation

The planetary missions typically have radiation requirements. The short range communication system need to survive the bombardment of high energy galactic particles en rout to the destination and may need to operate in radiated environments with little or no atmosphere. The radiation requirements depend on the orbits/trajectories, the operating environments, the duration of the missions, and the risk the missions are willing to accept. DS-2, for example, has no radiation requirement because it has a very short life time and will operate in a benign Mars environment. The requirements for total ionization dose for the missions surveyed are typically between 200 rads to 20 Krads. The communication systems may also need to be resistant to single event failures such as latch-ups, burn-outs, and gate raptures and be able to recover from single event upsets.

Multiple Access

When there is more than one surface element within the coverage of an orbiter such as Mars '01 Lander and Rover and several of the proposed Discovery missions, a multiple access technique is needed for the RU's to share the links to the orbiter. Typically, the command data volume is small. All RU's should be able to use one command channel to receive command from the orbiter through proper addressing schemes. The telemetry link from the RU's to the relay can be problematic as the RU's have to share the orbiter's receivers to relay their data back to the Earth. One solution to this problem is through frequency-division multiple access (FDMA). The orbiter can carry several receivers, each tuned to a different frequency band. The technique provides a simple solution since the number of remote units a master unit has to be communicate with at any given time is small. It does not require stringent timing control as in time-division multiple access (TDMA) systems or sophisticated power control as in code-division multiple access (CDMA) systems.

Navigation

Some missions may also rely on the communication systems to provide radio metrics for navigation and positioning. This function is especially crucial for Mars long-range rovers which may require the assistance of navigators on Earth. It is found that a simple one-way Doppler technique can provide the 1 Km accuracy required.[1] This one-way Doppler method requires both the MU and RU transceivers to have stable oscillators and two relay orbiter passes for an accurate positioning estimate. This technique does not impose any restriction on the forward link modulation and does not require a full-duplex link or a transponder for the RU. Other navigation techniques such as two-way coherent Doppler tracking and time-of-arrival measurements either require transponders or may not provide better accuracy than the one-way Doppler technique.

Doppler

The Doppler shift for Mars orbiters like Mars Global Surveyor is +/- 4000 Hz for carrier frequency of 400 MHz. Doppler is expected to be small for comet missions.

Shock

Shock requirements depends on the landing trajectories and methods. Mars '98 Microprobes have very high shock requirement of 80,000 g as the large impact force is used to penetrate part of the probes into the Martian soil. Other missions are not expected to have such high shock requirement.

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[1] Navigation study were conducted by William Folkner of JPL and Stanford Telecom. Both studies recommended the one-way Doppler technique.

Packaging

The packaging of the parts for the communication system need to be space qualified for outgasing, vibration, temperature, and other environmental factors unique to planetary missions.

Candidate MCAS Specifications

Of the basic sets of mission requirements the one with the most pressing needs is the asymmetric high data rate telemetry link coupled with the low data rate command link for communications between an orbiter and an in situ instrument. If adequately funded, the MCAS effort could deliver hardware for Champollion and Mars '01 missions which have the asymmetric data rate requirements. These along with DS-3, which has similar communication requirements, are thought to be the most immediate needs. The MCAS effort will, therefore, focus on detailing a design to meet the requirements of these missions.

A summary of specifications of the MCAS transceivers is shown in Table 1. The specifications reflect the results of the study and survey conducted and the best estimate of requirements that will allow for use by multiple missions. The MCAS transceivers will be compatible with the Mars relay infrastructure using the same frequencies and modulations. The additional transmit and receive frequency not specified is reserved for RU-to-RU communications. This frequency will be identical that of the Mars '01 Lander and Rover communication system. More telemetry frequencies will be added to the MCAS specification as they are defined by future Mars relay systems. The MCAS RU will have tunable telemetry transmitters and the MCAS MU will have tunable telemetry receivers. The MCAS RU transceiver will perform the (7,1/2) convolutional encoding for telemetry data. If an outer Reed-Solomon code is desired, the data needed to be encoded before arriving at the transceiver. Since the RU MCAS design does not include a Viterbi decoder, the RU convolutional encoder should be able to be disabled so that two MCAS RU transceivers can communicate with one another as in rover-to-lander communications. The MCAS MU transceiver will have a Viterbi decoder for the (7,1/2) convolutional code.

The output RF power is expected to be 300 mW. As in the DS-2 design, this RF power is sufficient for a 7 Kbps link between a Martian penetrator and a relay spacecraft at a 400 km orbit. For missions that require higher telemetry data rates, an external high power amplifier (HPA) is needed. If within shock, volume and mass constraints, a circularly polarized antenna can also be used to reduce the transmit power by half over a monopole antenna.

Table 1, MCAS transceiver specifications

	Master Units	Remote Units
Frequency Transmit Receive	 437.1 MHz[1], X MHz[2] 401.5275 MHz[1], X MHz[2]	 401.5275 MHz[1], X MHz[2] 437.1 MHz[1], X MHz[2]
Modulation Technique Transmit Receive	 BPSK BPSK	 BPSK BPSK
Data Rate Transmit Receive	 1 Kbps and 8 Kbps 8 Kbps, 64 Kbps, 128 Kbps, 256 Kbps, 2Mbps	 8 Kbps, 64 Kbps, 128 Kbps, 256 Kbps, 2Mbps 1 Kbps and 8 Kbps
Coding Transmit Receive	 None (7,1/2) Viterbi decoder[3]	 (7,1/2) encoder[3] None
Output Power	300 mW RF	300 mW RF
BER	$< 10^{-5}$	$< 10^{-5}$
Mass	Very low	Very low
Power Consumption	Low	Low
Full/Half Duplex	Full duplex	Full duplex
Temperature	-80° to 80° C	-80° to 80° C
Radiation Total Ionization Dose Single Event Effects (SEE)	 20 Krad Can recover from SEU Resistant to single event failure	 20 Krad Can recover from SEU Resistant to single event failure
Shock	80K g max	80K g max
Navigation	Accuracy of 1 Km or less[4]	Accuracy of 1 Km or less[4]

1. These transmit and receive frequencies are identical to the MSP 98 and BTTS specifications. These frequencies will be used for Mars ‘01 and ‘03 Relay. More telemetry frequencies will be added as they are defined by future Mars relay systems.
2. In order for two MCAS transceivers to communicate with one another, the transceivers must be able to receive and transmit at the same frequency.
3. If an outer Reed-Solomon code is needed, encoding and decoding should be performed outside of the MCAS transceivers.
4. 1 Km accuracy for Mars RU’s depends on the stability of the RU oscillators and the orbit of the Mars relay orbiter.

MCAS Development

In looking at the specifications for the Master Unit and the Remote Unit in Table 1, it becomes apparent that it should be possible to build a sufficiently flexible transceiver that satisfies the requirements of both the MU and RU. The block diagram for such a transceiver is shown in Figure 3. Since the motivation for MCAS is the development of a highly integrated, compact, low-mass, and low-power transceivers primarily intended for use by the RU these drivers must not be sacrificed for the sake of achieving a universal MU/RU transceiver. The transceiver can be designed such that various power consuming functions can be disabled (i.e., decoder, navigation) and the system clock rate can be run at low frequencies (i.e., low processing rates for the low data rate command receiver resulting in low power consumption) a sufficiently flexible yet high performance universal MU/RU transceiver is possible.

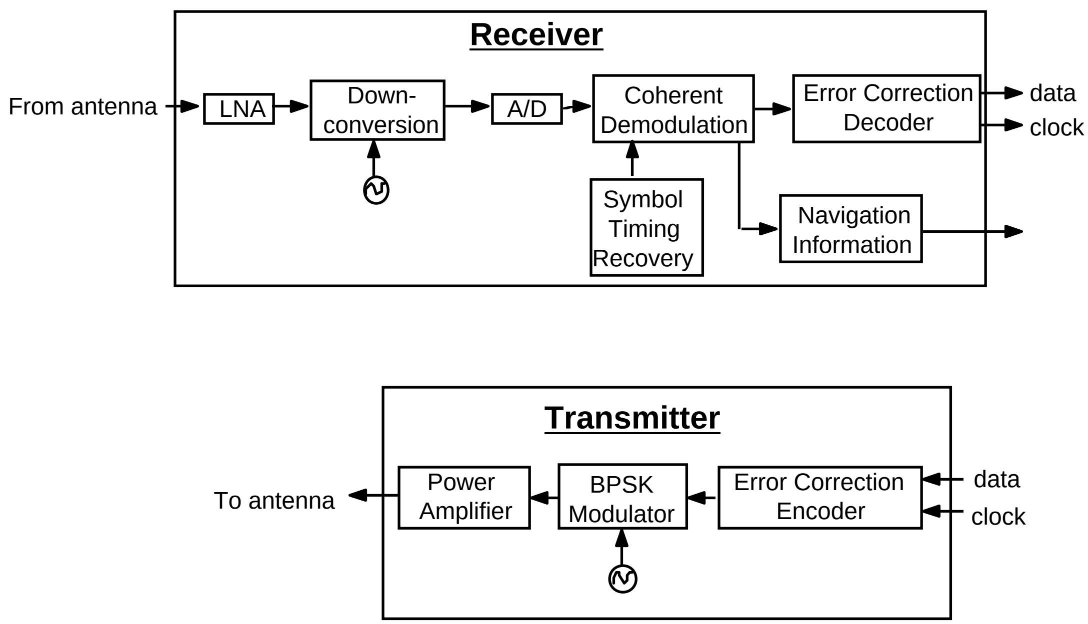

Figure 3 Block Diagram of a Flexible Master & Remote Unit Transceiver

The MCAS development plan is composed of three phases depicted in Figure 4. Each phase provides a functional transceiver and adds another level of integration over the previous phase. The point of performing the development in phases is that at the conclusion of a phase there will exist a transceiver that could potentially be inserted into a mission of opportunity. MCAS will stay in close contact with flight projects to ensure that this spin-off of MCAS technology occurs.

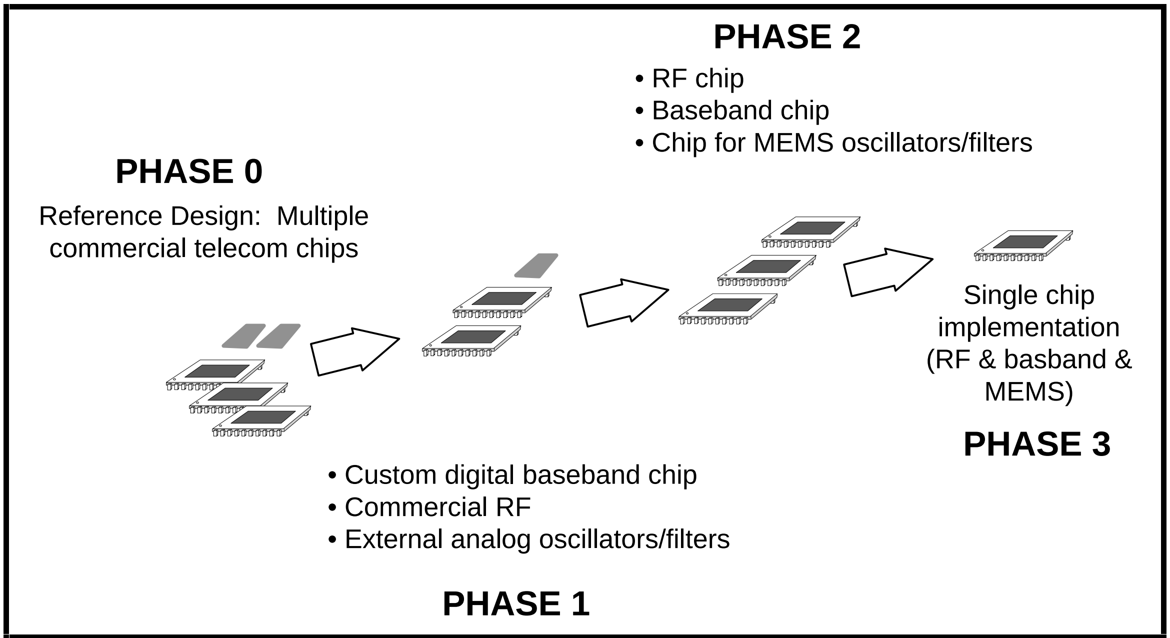

Figure 4 The MCAS Development Approach

As can be seen in Figure 4 the vision for MCAS at the end of Phase 3 is a single chip transceiver. The viability and prudence of fully integrating all transceiver functions on a single chip will become more obvious as the effort progresses. It should be noted that this end product is quite challenging especially if full duplex operation is to be achieved due to such considerations as RF/digital interference transmit/receive isolation. The three phases are described in more detail below.

Phase 1: MCAS1

Phase 1 starts with the design of a “reference” or “benchmark” design that is based entirely on the use of existing commercial parts. This effort is depicted as Phase 0 in Figure 4. The block diagram of the benchmark design is shown in Figure 5. This crude paper only design based on commercial parts is not planned to be built but rather to help assess what the limitations (e.g., power, radiation, size, etc.) are based on the current state-of-industry.

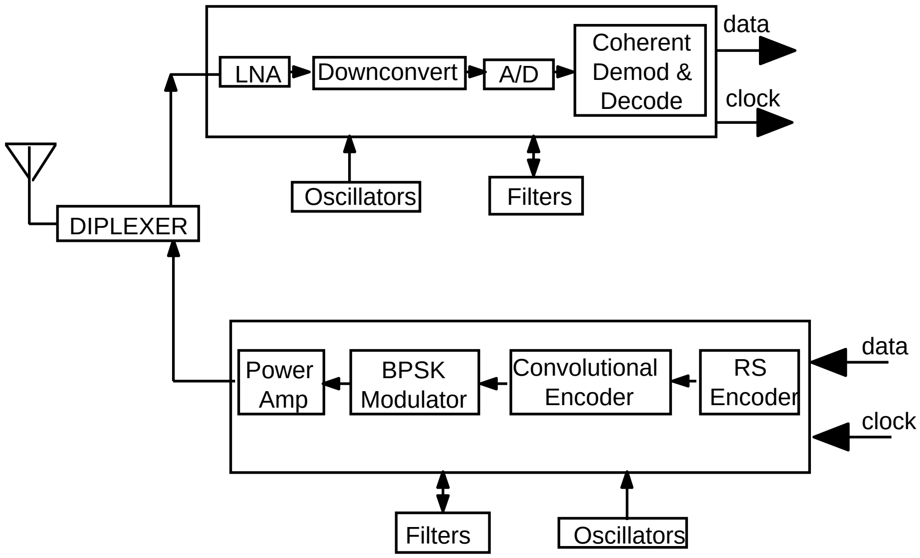

Figure 5 Commercial Based Chip Design (Reference or “benchmark” Design)

The first hardware to be built in Phase 1 will be as depicted in Figure 6 and Table 2. The basis for this design is that a custom ASIC all digital baseband chip will be designed and used in conjunction with a commercial based front end. It is expected that the digital ASIC design will carry forward into phases 2 and 3. The initial Phase 1 task list is provided in Appendix B.

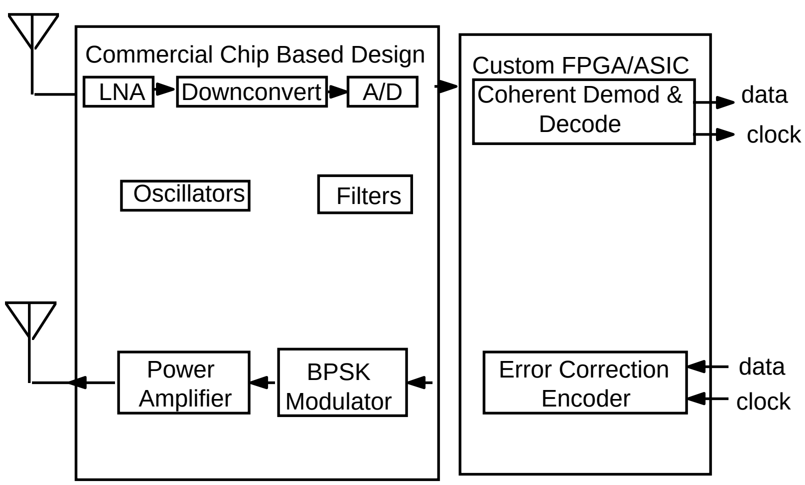

Figure 6 MCAS1 Block Diagram

Table 2 MCAS1 Target Specifications

DELIVER HARDWARE: PRE-10/99
FREQUENCY: 401/437 MHz
FULL DUPLEX
TRANSMITTER: BPSK
RECEIVER: COHERENT BPSK
TX POWER: 300mW / 1 mW (to drive external power amp)
8 / 128 KBPS (GOAL 2MBPS)
CODING: RS/CONV. OR TURBO
PACKAGING: MCM + DISCRETES
SIZE / WEIGHT: <7.5 IN^3 / <4 Oz. (~HP15C)
POWER: < 2W
SPACE QUALIFIED (RADIATION, SHOCK, TEMP.)
NAVIGATION: 1-WAY DOPPLER
PROTOCOL - TBD

An additional effort that is taking place in Phase 1 of MCAS is the funding of research at the University of Michigan to develop micro electrical mechanical systems (MEMS) based oscillators and filters that could be utilized by MCAS to greatly reduce the size (i.e., by a factor of 1/35,000) and power of the current state of the industry off chip implementation of such devices. Currently, the MEMS effort is focused on developing a temperature-stable 10 MHz reference oscillator, and filters at 10.7 MHz and 437.1 MHz.

Phase 2: MCAS2

Phase 2 will attempt to combine the Phase 1 digital ASIC design together with a custom RF ASIC and a MEMS based oscillator/filter chip to produce a transceiver. The starting point for the RF ASIC is to build on the DS-2 single chip transceiver work that is currently on going. It is expected that the transceiver will make extensive use of the analog circuit designs for the DS-2 chips where possible (e.g., LNA, analog downconvert, A/D, digital downconversion, modulator, upconversion, and frequency synthesis). The MEMS based components may be integrated on to a single die or my be individual MEMS oscillators and filters, depending on the progress of the developmental research taking place at the University of Michigan.

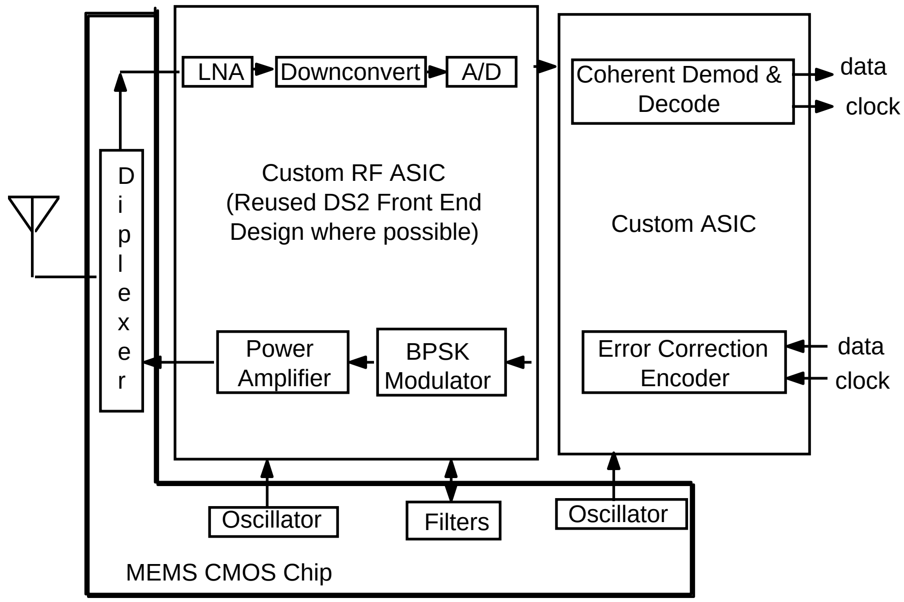

Figure 7 MCAS2 Block Diagram

Phase 3: MCAS3

The final phase of MCAS is also the most aggressive technically. MCAS3 calls for the full integration of the Phase 2 digital, RF, and MEMS designs on to a single chip as shown in Figure 8. As was previously mentioned this may in the end prove not to be viable or practical (e.g., an MCM may make for sense) but it is the stated goal at the outset of the MCAS effort.

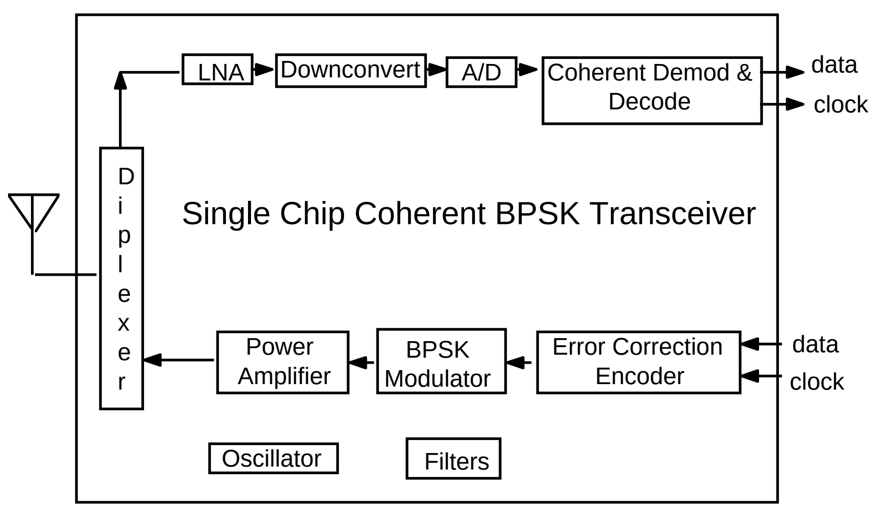

Figure 8 MCAS3 Block Diagram

Schedule and Budget

The schedule for the MCAS development effort and the funding profile are depicted in Figure 9 and Table 3 respectively. The DS-2 transceiver schedule is shown as a point of reference. Currently MCAS has a commitment for $940K of FY98 funds and the breakdown for their use is as follows: $250 K technology development (e.g., MEMS), $690 K MCAS1. Additionally a TBD amount of this funding will be allocated to investigation of communications design and development solutions for NASA's ultra short range communications needs (e.g., wireless sensors).

Table 4 lists the critical dates for several up coming missions that are potential customers for MCAS. The shaded missions in Table are currently considering use of MCAS products. The WBS for the MCAS effort is provided in Figure 9.

Figure 9 MCAS Schedule

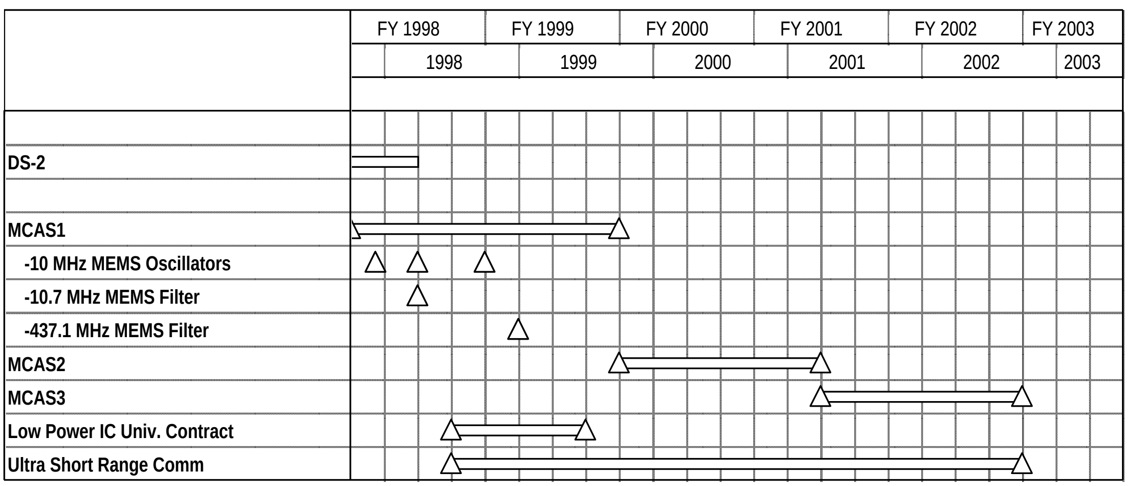

Table 3 Funding Profile

FY98	FY99	FY00	FY01	FY02
$1.5M	$2M	$3M	$3M	$2M

Table 4 Upcoming Missions with Potential Need of MCAS Products

Mission	Breadboard/CDR .	Engineering Model H/W	Comm. Flight H/W	Launch
Mars '01		12 /98	7/99	4/01
DS-3	2/99	7/99	4/00	12/01
Muses-CN			5/00	1/02
DS-4 (Champ.)	5/00	2/01	10/01	4/03
Mars '03				5/03
Mars '05				11/04
Jupiter Multiprobe				
Europa				
TBD..........				

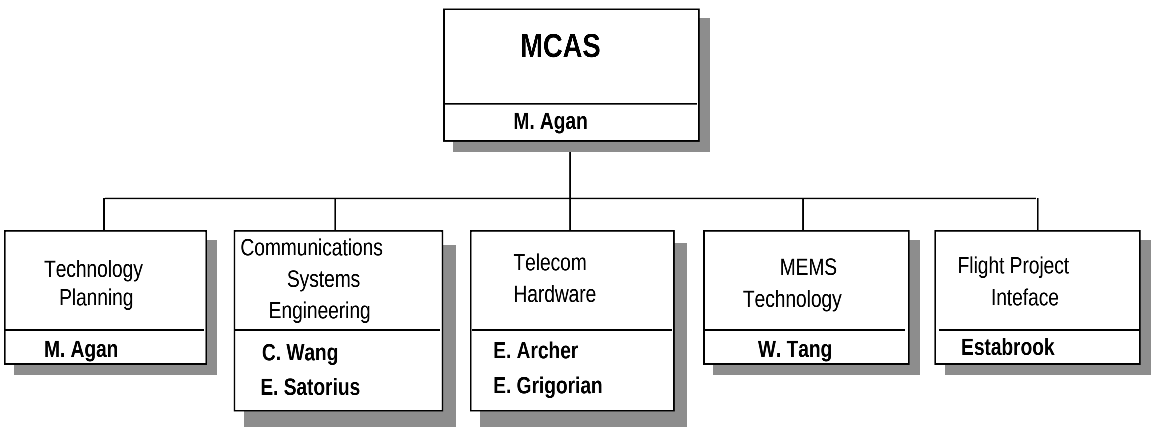

Figure 9 MCAS Work Breakdown Structure

Appendix A: THE DS-2 TRANSCEIVER

The New Millennium Deep-Space 2 (DS-2) transceiver is being designed for the Mars '98 Microprobes. The transceiver is currently expected to return from the foundry in December 1997. It will be used to communicate with the Mars Balloon Relay (MBR) transceiver carried by Mars Global Surveyor. The DS-2 transceiver is a highly integrated telecommunication chip designed specifically for short-range planetary missions. The chip is required to meet the low-mass and low-power mission specifications. It is designed to survive an impact of up to 100,000 g when the microprobes impacts Mars. The DS-2 has no radiation requirements and is being designed using a standard CMOS fabrication process. A block diagram of the DS-2 chip is shown in Figure .

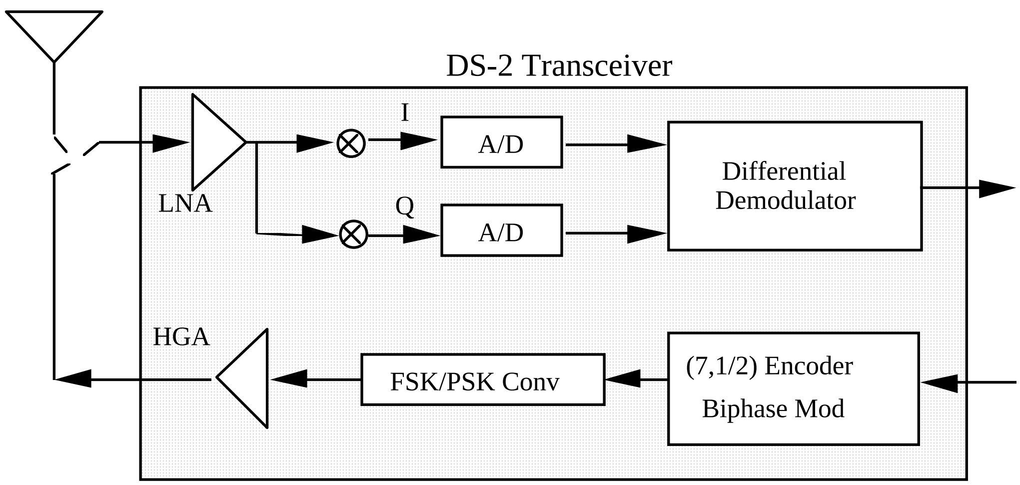

Figure A-1, DS-2 transceiver

The DS-2 transceiver consists of a half-duplex binary PSK transmitter and a tone receiver. It is half-duplex. In the received signal is downconverted, digitized, and then processed to determine which of the tones is sent by the MBR transmitter. The tone receiver is estimated to be able to support about several bits per second (~10 bps). The transmitter includes a (7,1/2) convolutional encoder with an output that biphase modulated before the PSK modulator. The PSK modulator uses a residual carrier with modulation index of 60 degrees (i.e. twenty-five percent of the transmit power is allocated to the carrier). The HPA generates 300 mW of nominal RF power when the DC supply is 6 V with an estimated 70 % efficiency. The transceiver can transmit up to 1 W if the DC supply is between 12 and 14 V. The power consumption for the tone receiver is 3 mW. It is expected to be able to transmit up to 500 Kbps.

Issues for a DS-2 Follow-On

The DS-2 chip is designed to be polled by the MBR. It has very limited receiving capability. The DS-2 follow-on design needs to be able to receive command data rates of 1 Kbps and 8 Kbps.

With the tight power budget, PSK should still be used for the DS-2 follow-on transmitter. More powerful FEC such as turbo codes should be considered. The current design has a modulation index of 60 degrees which corresponds a 1.25 dB loss. It has been shown that the residual carrier is not needed for the data rates of interest (8 Kbps or more).

The current DS-2 design can perform Reed-Solomon encoding up to 8 Kbps using the on-chip processor. To support high data rate missions with tight power constraints, the DS-2 follow-on transmitter will need to include a Reed-Solomon encoder at 128 Kbps or higher.

The DS-2 follow-on transceiver should also be full-duplex. There are implications to have the analog portion of the transmitter and receiver on a full-duplex transceiver chip due to cross-talk. The difference in the analog signal strength between the transmit and the received signal can be very large and small leakage of the transmit signal into the receive path can severely degrade the performance. Separate receiver chip and transmit chip may be the best solution, although further investigation is needed.

If FDMA is chosen as the multiple access scheme, tuning circuit for the RF oscillator will be desirable. In addition, a pulse shaping filter may be needed for the transmitter. Due to the significant sidelobes of the current design using biphase modulation, the frequency-division channels have to be significantly far apart to avoid interference.

Another issue that requires closer examination is the data protocol design. A more robust and efficient data protocol than MBR’s BTTS is needed especially when there are more than three surface elements in the view of the orbiter. A more flexible addressing scheme is needed. The new protocol should also support different levels of priorities. In addition, ARQ techniques can be added to improve the link performance via acknowledgment (ACKs and/or NAKs). Further investigation is also needed to see if it is possible to modify the DS-2 transmitter into a transponder if the two-way coherent navigation method is required.

Appendix B: PRELIMINARY PHASE 1 TASK LIST

Requirements Definition

- generate a requirements document
- data rates, tx/rx frequencies, candidate link budgets, Doppler, phase noise, radiation, SNR, navigation, temperature (survive and operate), required tenability, dynamic range, frequency offsets (for acq & tracking due to Doppler and oscillator drift), shock, vibration, etc.

Systems Issues

- need for pulse shaping
- tenability of tx and/or rx
- protocol
- multirate receiver design
- packaging issues: for intermediate systems, flight requirements, outgassing of plastic RF parts, (mcms)
- Radiation (Should we build for TID of 100 Krad for Europa type of environment or 20 Krad for Mars and Champollion type missions?)
- Differential encoder and decoder
- Conv. encoder (should have the option of being disabled)
- Phase modulator (different symbol rates; may be nice to be able to change mod index; Can this be done digitally?)
- Manchester code

Algorithm issues

- coherent demod scheme
- coding decoding (use of low complexity turbo code vs concatenated)
- AGC
- AFC
- Acquisition time
- navigation algorithm
- modulator
- how to implement variable data rates (carrier tracking loop for low SNR signal at low data rates)
- open loop vs. closed loop algorithms
- Carrier tracking loop (Costas loop vs squaring loop; Digital vs. digitally-controlled analog; Order of the loop; DC offset; Doppler tracking (may have residual tracking errors if 2nd order loop used); Acquisition (how long, training sequence?); False frequency lock (may need FFT or discriminator) for Costas loop (same problem for

SQ loop?); Phase ambiguity; Simple passive arm filter or integrate and dump filter; loop bandwidth; SQ loss; lock detector (compute threshold))
- Symbol tracking loop

Hardware Architecture Issues
- key: being low power & low gate count
- when to produce MCM's vs. single chips
- front end / A/D architecture (# of stages of down conversion vs. #bit on a/d vs. a/d clock rate vs. power consumption)
- clock and LO generation and distribution
- data rate limitations on receiver
- how to get full duplex; size of the diplexer
- implementation low power of sleep / receive / tx modes
- FPGA design; translation of FPGA to ASIC
- design of analog/RF ASIC
- nco's vs. vco's for frequency sources
- diplexer solutions: full vs. half duplex
- IF frequencies and number of stages
- Bus Interface
- Image rejection filter?
- oscillator stability; operate in wide range of temperature (-120 C to +85 C); Allan variance)
- testing plan (including MEMS testing)

Chip Design Issues
- survey state of industry in IC transceiver design
- investigation of appropriate radiation hard process
- power amp and LNA on same chip
- thermal analysis
- power/weight estimates (compare to current solutions)
- what design elements can be carried over from DS 2, tiny?
- identify areas of research for low power techniques (UCLA)

Performance
- analysis
- floating points simulations

- fixed point simulations